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REPORT OF THE HEMLOCK LOOPER OUTBREAK IN SOUTHWESTERN WASHINGTON AND ITS CONTROL THROUGH AIRPLANE DUSTING

By
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Entomologist
U. S. Bureau of Entomology

Portland, Oregon
Dec. 10, 1931.

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CONTENTS

INTRODUCTION.

The hemlock looper is a forest defoliator with a very bad reputation for destructiveness and reports of its activities are always viewed with alarm by owners of timberland in the coastal fog belt of Oregon, Washington and British Columbia.

In the past forty years, two major outbreaks have been recorded on the coast of Oregon and Washington. The earliest outbreak occurred about 1889 to 1891 and destroyed a vast amount of timber in Tillamook and Clatsop Counties in Oregon and in the Gray's Harbor region of Washington. The second outbreak of major importance occurred in 1918-1921 in Tillamook County, Oregon. This epidemic is reported to have killed 500,000,000 board feet of hemlock and fir. In each instance the outbreaks lasted about three years and then were brought under control by natural agencies.

The first report of the present outbreak was received by the Weyerhaeuser Timber Company in the fall of 1930 from their cruisers working in southwestern Washington, and in November this report was investigated by the writer accompanied by Mr. Buckhorn, also of the Bureau of Entomology and Mr. Nethery of the Weyerhaeuser Timber Co. The moths were still in flight and it was soon evident that the damage was due to defoliation by the hemlock looper- a reappearance after an absence of nearly ten years. No further examinations were made during the winter as the loopers were then in the egg stage and very difficult to find, but in the following April and May the general area was scouted and additional defoliated areas found (Memo. of April 29, 1931.)

THE AREA.

The affected area lies in Pacific County, of southwestern Washington, on the Naselle and Nemah Rivers. (Townships 10, 11 and 12 N, Ranges 9 and 10 W). This is a country of medium rough topography, with low mountain ranges cut by deep ravines and indented by sloughs and arms of Willapa Harbor. Very little of the area could be called flat, although some parts are gently rolling. Practically the entire area is covered with a dense stand of hemlock timber and an almost impenetrable jungle of brush, mainly salal, salmonberry, huckleberry and devil's club. Very few roads penetrate the area and there are no lookout points, so that scouting the area is an extremely difficult task.

The timber on the area is for the most part a culled virgin forest, principally of hemlock with some Sitka spruce, and western red cedar. During the war most of the area had been culled and the best trees, particularly the spruce, had been logged out. Other tracts were completely cut over and are now covered with second growth or in many cases simply a dense thicket of logs and brush. The stand averages about 30 M. bm. per acre, of which 80 percent is hemlock, 15 percent sitka spruce and 5 percent western red cedar. Some of the best stands will average 45 M. bm. per acre. Hemlock stumpage is only valued at from 50 cents to $1.00 per M. bm., but the cedar and spruce

is much more valuable, running from $2.00 to $4.00 per M, depending upon quality and accessibility.

The Extent of the Present Looper Outbreak.

On the basis of the first examination made in November 1930, it was estimated that about 5000 acres were infested with loopers, of which 500 acres were hit severely enough to show at least 50 per cent defoliation. Subsequently, during the spring (Memo of April 29th) additional scouting was done and fully 6000 acres reported as heavily defoliated by the 1930 brood of loopers. Of this area approximately 2100 acres were defoliated heavily enough to be killed.

The 1931 infestation was notably widespread but not until the fall of the year, after feeding was completed, could the full extent of the year's activity be determined. The total known acreage infested by loopers in the Naselle area is now approximately 32,000 acres. Of this 11,500 acres have been heavily defoliated and a total of 5400 acres killed.

The estimated progress of the looper epidemic is shown in Table 1, which indicates that 162,000 M board feet have been killed to date. If the reports of the local loggers as to the defoliation and killing in 1929 is correct, then there must have been some infestation in 1928 for this outbreak could not start from nothing. Therefore, 1928 is probably the real beginning of this outbreak, and 1931 represents its fourth year. This table also brings out the reduction which was secured as a result of the airplane dusting. This point will be discussed later in the report.

TABLE NO. 1

Progress of Looper Outbreak
in
Pacific County

Season	Total Acreage Infested	Acreage Heavily Defoliated or Killed	Acreage Killed Each Year	Volume Killed per Acre M. BM.	Total Volume Killed M. BM.
1929	3,000	1,000	300	30	9,000
1930	10,000	6,000	2100	30	65,000
1931	32,000	11,500	3000	30	90,000
Total	32,000	11,500	5400		162,000

THE LOOPERS THEMSELVES.

In order to understand the details of the looper control problem, it will be well to first briefly review the characteristics of this insect in its various stages.

The hemlock looper (Ellopia fiscellaria var lugubrosa Hulst)[1] is a moth of the family Geometridae or measuring worm family. It goes through four stages or transformations during its life cycle - the egg, the larva or caterpillar, the pupa or resting stage and the imago or adult moth.

The eggs are irridescent light gray-green to brown, about 1 mm in diameter, and are attached to the moss on branches or tree trunks. The larvae are slender, practically hairless, light green caterpillars with a few dark spots and markings. When full grown they are about 1½ inches long. They are known as "measuring worms," "spanworms" or loopers on account of their very characteristic mode of travel, which consists in alternately extending the body and then arching the back to bring the rear end of the body forward. On hatching they ascend the tree and feed on the tender new growth. As they become larger, their feeding becomes more and more destructive, especially since they have the habit of feeding at the base of the needles and cutting them off so that more food is wasted than consumed. When all the needles are eaten on any particular branch, the caterpillars let themselves down by means of a silken thread which they release through their mouth parts. When the caterpillars are abundant, the forest becomes one vast "spiderweb" of these larval threads.

The pupa or resting stage consists of a mottled greenish brown chrysalis about 1/2 an inch long which is secreted in crevices of the bark, in moss or under debris on the ground.

From these pupae, the adult moths emerge. They are a tawny to light buff in color with a wing expanse of about 1½ inches. The wings are marked with two wavy darker lines.

Seasonal History.

The moths emerge from their cocoons and fly during late September, October and early November. The eggs are laid mostly in the moss on the tree trunks but may also be placed on needles, branches and on brush. The winter is passed in this stage.

The following spring in May and June the eggs hatch and the young larvae crawl up the tree trunks and start their attack upon the young needles. This year (1931)hatching of eggs started on the 10th of May and continued until about the middle of June. In the younger

[1]Determination by Mr. Carl Heinrich.

stages considerable feeding is done on huckleberry, salal and other undergrowth, but as the larvae increase in size they transfer activities to the hemlock. The lower foliage is first eaten and the larvae gradually work their way upward. By the middle of July their inroads into the tree's foliage is very noticeable and the new areas of defoliation can be recognized.

The caterpillars reach full growth and the peak of their feeding by the middle of August and start pupating. Pupation reaches its height by the first of September and practically all larvae have pupated by the middle of September. This transformation takes place in the moss on the trees, in crevices of the bark or under debris on the ground. Flight of the moths again occurs in October, thus completing the life cycle.

Habits.

All of the destructive feeding is done by the caterpillars largely at the base of the needles so that the needle is cut off and falls to the ground, thus more foliage is destroyed than is actually eaten. As the caterpillars increase in size the stems and small twigs are chewed off so that the ground is strewn with the small tips of twigs. The destruction of buds in this way is probably the reason why the feeding of the loopers is so destructive to the trees, and prevents their recovery.

Effect of Weather Conditions Upon the Loopers.

Temperature.

The development and growth of the loopers is dependent upon satisfactory temperatures, but since the climate in this region is a mild one, unfavorable temperatures can hardly be expected. It was very noticeable that the feeding of the caterpillars varied according to weather conditions and accelerated markedly during hot days. Chart #1 illustrates this point. Here the average of the daily droppings for plots #4, #5 and #6 is compared with the summation of degree-hours above 50° F. July 6th, 7th and 19th were exceptionally hot days and the influence of these days upon the feeding is very marked. Some minor fluctuations are also noticeable. (The record of droppings is for the day of collection, so really represents the accumulation of the previous night and day. This explains the apparent lag of one day.)

By accident a glass jar containing caterpillars and fresh foliage was left in the sun for two hours. The temperature inside the jar reached 120° F, accompanied by high humidity. All the caterpillars were killed. However, high temperature control cannot be expected in Nature for the temperature in this region rarely if ever, gets above

100°F. Critical low temperatures were not determined but fatal low temperatures are probably never reached in this region where the mercury rarely gets below zero.

Rain.

The cold, rainy weather during June apparently retarded the feeding of the loopers to some extent and caused them to spend considerable time under the shelter of leaves, particularly the larger salal and huckleberry leaves. For a while it was thought that this wet weather would permanently retard them and also cause a high mortality among them. Later this proved to be not the case. When the weather cleared, no very marked increase in feeding occurred, and the loopers continued with their work as though no change had taken place.

Wind.

At no time during the summer were strong winds in evidence. But daily an off-shore wind came up about 9 O'clock and blew more or less steadily during the remainder of the day. These winds caused a constant stirring of tree tops on exposed western slopes and ridges. And it was particularly noticeable that this wind movement was sufficient to disturb the caterpillars and prevent defoliation on such exposed sites. When the loopers are in the younger caterpillar stages any shaking of the branches will cause them to let themselves down by threads. This may explain why they avoid these exposed situations. The windward slopes were rarely attacked while the most damage was invariably found on the leeward side of ridges, in canyons, pockets, basins and draws where the wind does not ordinarily strike with any violence. If one stood on the Haselle bridge and looked up the river in the direction of the prevailing wind, not a single spot of defoliation could be seen. But from the dike road looking down the river defoliated areas were everywhere conspicuous. This distribution of the defoliated areas was also very noticeable when the forest was viewed from an airplane.

Character of Stands Affected.

The loopers show a preference for stands containing a high percentage of hemlock of thrifty to mature age classes. In such stands trees of all ages will be attacked, but the infestation seems to avoid stands of reproduction or poles. When such stands are encountered the defoliation usually stops abruptly. The younger trees are not avoided, however, when mixed with the older stands.

While hemlock is very decidedly the preferred host, western red cedar was frequently killed in cases where trees were located in groups of heavily defoliated hemlocks. Likewise a few spruce trees were also fed upon under such circumstances but rarely killed. In

areas where the loopers were particularly abundant all the shrubs and vegetation were fed upon as well as the trees. Huckleberry, and salal were favored shrubs when the caterpillars were small and during rainy weather the small larvae rested under the umbrella-like leaves and fed upon their shelter. No Douglas fir was found in the affected area so the preference of the caterpillars for this tree was not noted. However, in other outbreaks it has been recorded as destroying great quantities of Douglas fir timber.

Results of Defoliation.

In order to determine to what extent trees might be defoliated and still survive a set of 100 trees which had been defoliated to varying degrees during 1930 were examined on April 25, May 19 and 20, 1931 marked and tabulated as to degree of defoliation. The percent of defoliation was merely estimated as there was no way of taking an accurate measure. These trees were again examined on September 15 and 16 to determine how many had died during the summer.

In a number of cases where the crown still showed a few green needles and the cambium was still fresh, the trees were put in the questionable class since it was still uncertain whether they might live or die. Wherever Ambrosia beetles had entered the wood the tree was classed as dead, since these beetles only select dying or dead sapwood for their activities.

For the first year following defoliation the results were as follows:

TABLE NO. 2

Percent of Defoliation	Trees still alive	Recovery Uncertain	Trees Dead	Percent Dead
0 - 50%	13	0	0	0%
50 - 75%	5	13	0	0%
75 -100%	1	25	30	54%

The probabilities are that none of the trees less than 50 per cent defoliated will die; and many trees with from 50 to 75 per cent of their foliage gone stand a good chance of recovery. Trees more than 75 per cent defoliated will probably all die.

The records also indicate that trees with the most vigorous crowns stand the best chance of resisting defoliation and death. Comparing the results of defoliation by four crown classes, the following interesting results were secured:

TABLE NO. 5.

	Trees Still Alive	Recovery Uncertain	Trees Dead	Percent Dead
A. Dominant (Full vigorous crown - 65% or more in length)	2	1	0	0%
B. Codominant (Short vigorous crown less than 65% in length)	16	25	25	38%
C. Intermediate (Small brush top or slim intermediate crown)	1	10	4	27%
D. Suppressed	0	1	1	50%

The same tabulation by age classes brought out very little significant differences, largely because the stands in which the records were taken were all of approximately the same age. In general, it was noted that the older stands were more susceptible than the younger ones.

THE AIRPLANE DUSTING.

Preliminary Plans.

On receiving verification of the presence of the hemlock looper in the Pacific County area, various plans of control were considered by the owners, but airplane dusting seemed to be the only possible solution in view of the extensive area affected and the quick action essential if the timber was to be protected.

At a conference of State and Company officials, it was decided that the first thing needed was an adequate survey of the situation to determine the extent of the area affected, where control could be applied most effectively and the cost of a dusting program. Since to secure such data from the ground was highly impractical on account of the density of the forest cover and the inaccessibility of the area, it was suggested that an aerial map was the only solution.

Through cooperation with the Forest Service the use of an aerial camera was secured and Mr. Lage Wernstedt was detailed by the Forest Survey to take the pictures. The plane was furnished by the

Northwest Air Service and piloted by Mr. John Blum.

On May 29th the photographs were taken and the vertical pictures secured were made into a mosaic map covering about 40 square miles. While an excellent map was secured in this way, the pictures failed to differentiate the defoliated areas and so the usefulness of the map was considerably impaired. It proved to be most valuable later in directing the dusting operations and giving the pilot topographic features to go by in laying down the dust clouds. The cost of making the map was approximately $257.60 plus contributed services.

On June 5th, the seriousness of the hemlock looper outbreak was presented to Governor Hartley of Washington by Company, County and State officials with an appeal for State cooperation in the protection of intermingled State forest lands. The Governor approved State cooperation to the extent of half the cost of work and this timely action on his part made the dusting project possible.

Steps were then taken to secure the calcium arsenate dust, secure bids for the flying and construct a hopper for carrying the load of dust and releasing it as required. There were numerous, unavoidable delays in getting the work organized but these made very little difference for it rained almost constantly on the area all during June and the work could not have been started even if everything had been in readiness. When the weather finally cleared, soon after the first of July, plane and equipment were ready to begin the dusting operations.

Control Strategy.

From an examination of the area made in April the extent of the looper damage and its status at that time was roughly determined. In a memorandum dated April 29th the writer reported: "(1) That 1930 was the second year of the outbreak rather than the first as had been previously supposed (although it was the first year so far as certain of the spots north of the river were concerned.) (2) That fully 6000 acres have been heavily defoliated instead of 500, and that there are possibly other areas which have not as yet been located. (3) That in respect to the economics of control, the ratio of the area to be dusted to the area to be protected instead of being about 1 to 10 as previously supposed, is more probably nearly 1 to 2. The cost of control is also increased fully ten times and is now so great that it is more or less out of the question to consider dusting to control the entire outbreak. (4) The only thing that can be done is to dust certain highly valuable tracts to protect them until the epidemic has passed. On this basis each tract must justify the expense of its own dusting, since no credit can be given for the protection of other areas."

Since the epidemic had been in progress at least two years, eggs had undoubtedly been widely distributed over an area of probably

10,000 acres. (Later found to be 32,000.) To dust this entire country in the hope of catching every looper was obviously impractical and futile. The dead and dying trees of the two previous years occurred in patches and strips and it was determined that the heaviest infestation occurred in the green timber adjacent to these old areas. Unless the loopers in the green timber were killed the areas of completely defoliated timber would greatly enlarge and coalesce. If, however, dusting of such heavy centers would serve to reduce the concentration of loopers by even 50 per cent, the trees would be able to survive the attack and much timber would be saved until nature took the outbreak in hand, as had happened in all previous outbreaks.

Therefore, the control strategy aimed to carry on the dusting only of the areas of heavy looper concentration with the hope of so reducing these centers that 100 per cent defoliation of the timber would be prevented and that the force of looper outbreak would be shattered. Hope was not held out that the dusting in itself would put a stop to the epidemic; it was merely a case of saving as much timber as possible until the epidemic spent itself.

Control Organization.

Mr. C. S. Cowan of the Washington Forest Fire Association represented the private timber owners and had general field supervision of the project. Mr. T. S. Goodyear of the State Division of Forestry represented the State's interest in the project and took charge of the loading operations at the beach. The writer, assisted by Mr. Beal, Buckhorn and Hallander, kept a check upon the distribution of the dust in the field and its effect upon the loopers.

Ocean Park, Washington, was selected as the base of operations. Permission was secured for landing planes upon the beach and the County provided two special deputies to guard the landing field and avoid accidents. A loading platform was built above high water, where the plane could be quickly loaded from a storage hopper. The dust was hauled by trucks and stored in improvised warehouses near the beach and the personnel were quartered in this small summer colony settlement. The beach was about 7 miles in air line from the infested area and about 30 miles by road. No satisfactory telephonic communication was available between the field and the beach and so code signals were resorted to.

Operations.

The actual dusting operations started on July 3rd and continued until July 16th when the total of 55½ tons of dust had been spread. A total of 117 trips were made requiring 53 hours and 9 minutes flying time. From 2 to 14 trips were made each day with an average of 8½ per day. The average load of powder was 920 pounds.

On the first and last day Mr. John Blum, President of the Northwest Air Service Co. piloted the plane; the remainder of the flying was done by Pilot Wesley Gray. Since flying had to be done close to the tree tops, at a height of approximately 40 feet, the work was exceedingly dangerous and considerable credit should be given to the pilots for the very clever manner in which the plane was handled and that in spite of the hazard no serious accidents occurred.

The Plane

The airplane used was a Ryan monoplane equipped with a 500 horsepower Wright whirlwind motor, a ship similar to that used by Lindbergh in his flight across the Atlantic. The ship and motor functioned perfectly throughout the job, which was fortunate since the slightest failure to function would have meant a crash in the tree tops. The 500 horsepower was invaluable for maneuvering over the rugged terrain and in at least two instances brought the ship through safely where any less powerful motor would have been inadequate. High power and easy maneuverability are essentials in work of this character. The calcium arsenate dust tended to "cake" badly on the aerilons, rudder and controls and had to be frequently chiseled off to keep these parts in working order.

The Dust Hopper.

An especially constructed hopper was built to carry a thousand pounds of dust along the general lines designed by Dr. Coad for cotton dusting work. The hopper was fitted in the rear cabin, a hole cut in the bottom for the sliding gate. This gate was operated by a lever in the pilot's compartment and could be opened and closed as desired. The opening was 27" x 5¾" or 111.75 sq. inches. No ventura tube was used.

Two agitators were installed to keep the dust in motion, one near the opening and one higher up in the hopper to bring the dust down. Since air propellers had given trouble as a source of power, an electric motor, which was run by storage batteries, was installed to operate the agitators.

The hopper worked very satisfactorily; about the only trouble was had with the operating lever which had to be greatly strengthened. The agitators gave some little trouble and on one occasion the gate stuck and refused to close. In view of the very considerable difficulties which have been a frequent source of trouble on other dusting operations, it is felt that this design was very satisfactory indeed.

The Dust.

A mixed dust with 20 per cent calcium arsenate content (As_2O_5) was recommended for use on this project and was ordered by the State

but the regular 40% calcium arsenate orchard dust was supplied instead and used without dilution. This dust had a greater bulk per unit weight than the 20% dust and consequently only 900 pounds could be used in the hopper which had been designed to carry 1000 pounds. It is thought that the mixed dust would have had better adhesive qualities.

Application of the Dust.

The contract with the Northwest Air Service Company called for the flying to be done at a height of 40 feet above the tree tops. Due to the rugged topography over which much of the flying was done, it was, of course, impossible to maintain that height without excessive hazard to plane and pilot. It must be said for the pilot that he did his best to comply with that clause of the contract and the flying was all done at a perilously close distance to the tree tops, but it was impossible, of course, to fly down into all of the canyons and still come out over the ridges, so that dust was often liberated a hundred feet or more above trees in the bottoms of narrow canyons.

The plan of dusting called for the application of dust at the rate of 20 pounds per acre. Taking into account the speed of the plane and the height of the flight, it was estimated that each dust strip would cover approximately 140 feet on the ground. It was soon found that this was a very theoretical figure, since even with a slight wind the dust would drift through the trees and spread out anywhere from 140 to 1000 feet depending upon the configuration of the country and the local air currents. Different parts of the same dust cloud were apt to behave very differently and frequently drifted in opposite directions.

There was no feasible way of marking out strips with flags or other indicators. After twelve hours of difficult and dangerous work, Buckhorn succeeded in placing flags at the tops of four hemlock trees spaced 280 feet apart. Each tree climbed was well over 150 feet in height but barely reached above the general level of the forest canopy sufficiently to be picked up by the pilot. Further attempts at flag strips had to be abandoned.

To give the pilot an idea of the distance apart of 140 feet flight lines, the writer and Buckhorn attempted to give the pilot signals for the dusting of one block of timber which was bordered along its northern edge by an old cutting. An old spar tree plainly visible on the aerial map was selected as a starting point. After an early breakfast, we left camp at 4:00 A.M. when it was first light enough to make one's way through the woods. It took an hour to traverse the quarter mile distance between camp and the spar tree, which was reached just in time to give the signal for the first flight at 5:00 A.M. In the time that it took for the plane to fly a mile south, turn and return, we had great difficulty in reaching the next point, 140 feet distant, for the starting of the next strip. A ten foot deep

jungle of salal, salmonberry and old logging debris is not a ground surface covering that one can make time through. For areas not bordered with openings, this method was, of course, not practical since the pilot could not see through the crown canopy to discover anyone on the ground.

Directing the flight lines from the ground, therefore, had to be abandoned and the dusting was left largely to the judgment of the pilot. An area was blocked out on the aerial map, with natural topographic features for boundaries, the amount of dust necessary to cover the area computed and the distribution turned over to the pilot. As a consequence the coverage was inevitably irregular and patchy. Some spots received double doses while others went without. In some places, due to driftage, the coverage was very light; in other places, especially below the path of the plane when it was near to a ridge, the dosage was especially heavy.

Atmospheric Influences.

Weather conditions have a very important bearing on the conduct of an airplane dusting job. It is obvious that dusting cannot be carried on during periods of fog, rain or high winds. It is equally important that atmospheric humidity must not be too low, that dew accumulates on the foliage during the night and that rains do not follow too quickly upon the heels of the dusting work. All of which means that the conditions for satisfactory dusting are exacting and the progress of the work is dependent upon weather more than any other factor.

Weather Conditions on Area.

During May there were nine rainy days and 2.05 inches of rain fell. June was a much wetter month with 17 rainy days and3.98 inches of rain. The weather cleared on July 3rd and then turned hot while the humidity dropped to a low point during the middle of the day. This condition accompanied by drying east winds, continued until July 8th when the characteristic morning fogs of this coast belt put in appearance and raised the atmospheric humidity especially during the morning hours. This condition prevailed through the remainder of the dusting period and more or less for the remainder of the month, except that on the afternoon and night of the 12th, and again during the night of the 15th, 3/16 of an inch of rain fell. The weather cleared again on the 14th.

Effect of Humidity.

The most important effect of humidity was its influence upon the adhesive quality of the dust. To secure good adhesion the foliage should be damp. If it is dry the dust shakes off the leaves with the slightest breeze. For this reason dusting was done only in the early morning, for the most part on days when the humidity was high. When the sun came out and the humidity dropped, the dusting was stopped.

Rain.

The only rain which fell during the dusting period was on

the nights of the 12th and 13th. About 3/16 of an inch fell both nights but came so gently that it is doubtful if very much of the dust was washed from the foliage. The damp foliage made ideal conditions for good adhesion, on the following days.

Wind.

No strong winds were met with during the dusting period, but during the day any wind in excess of 5 miles per hour, increased the flying hazard and also tended to cause the dust clouds to drift erratically. Most of the dusting was done in the morning hours before the wind came up.

Amount of Dusting Accomplished.

At the rate of 20 pounds per acre, the 53½ tons of dust should have covered 5350 acres. However, as previously shown, the distribution was far from uniform and the actual distribution was more nearly as shown in Table No. 4.

On Area 1, the infestation was very patchy and spots representing about 600 acres were dusted out of a total of 1300 acres in this area.

Also in the large area south of the Naselle River, only some of the newer and more accessible spots, representing about 1800 acres out of the total of 7000 acres in this area, were dusted. The extreme flying hazard and the advanced stage of the outbreak in this area made its protection an almost hopeless undertaking, so that much of it, already past hope of saving, had to be abandoned.

Thus the dusting was confined to an infested area of 11,500 acres, of which 5400 acres were dusted with an average dose of 20 pounds of calcium arsenate per acre, while portions of the area received dosages ranging from 0 to 55 pounds per acre.

TABLE NO. 4

Area	Sections	Total Acreage	Acreage Dusted	Dust Applied	Dosage per acre
1	24, 25, 36	1300	600(1)	11,000 lbs.	18 lbs.
2	(1 & 2	800	800	16,000 "	20 "
	(12 & 13 E 1/2	700	700	12,000 "	17 "
3	(3	100	100	1,800 "	18 "
	(2, 10, 11	500	500	10,000 "	20 "
	(13 W1/2, 14	200	200	11,000 "	55 "
4	32, 33	900	700	9,000 "	13 "
5	(S of Naselle River	7000	1800(2)	36,000 "	20 "
Total		11,500	5400	107,000 lbs	20 lbs.

(1) Representing spots in a total area of 1300 acres.
(2) Representing spots in a total area of 7000 acres.

Cost of Dusting.

As stated by Mr. Goodyear in his report dated July 27th and later corrections, the total cost of the operation was as follows:

TABLE NO. 5

Expenditures

Aerial map		$257.60
Construction of loading platform		
Material & labor - Willapa Harbor Iron Works	$56.00	
Gas, oil, etc. for truck - Truedson & Brown	11.06	
Material & Labor - F. C. Foster Co.	5.67	
Sundry labor on loading platform	37.40	
	$108.13	108.13
Cost of dust		
54 tons calcium arsenate less discount for delay & substitution	$ 4736.29	
Storage of dust (Ocean Park)	15.00	
	$ 4751.29	4751.29
Flying time - 53 hrs. 9 min. at $160.00 per hr.		8504.00
Total Cost		$13,621.02

Funds for the work were contributed as follows:

Contributions

State of Washington	$6,810.51
Weyerhaeuser Timber Co.	4,620.44
Pacific County	924.08
Washington Forest Fire Ass'n	924.08
Mason & Stevens	221.78
Northern Pacific Railway Co.	73.93
Illinois Timber Co.	46.20
	$13,621.02

Labor contributed in addition to the above was approximately as follows:

Pacific County	$500.00
Washington Forest Fire Ass'n & State	500.00

The average cost per acre dusted (on the basis of 5400 acres dusted) was approximately $2.71 per acre; or a protection cost of about 9 cents per thousand board feet for the area actually dusted. Any benefit which the dusting may have had in protecting areas outside of those actually dusted is an added saving not considered in the above.

Toxic Effect of Arsenic on other Animals.

Considerable anxiety was expressed by various residents in the vicinity of the control area as to the possible effect upon domestic animals and humans of the spreading of so many tons of arsenic dust in the region.

There is ample proof to show that there was no need for alarm. A report of Mr. Charles M. Smith, Insecticide Division of Bureau of Chemistry & Soils, states that "the tolerance for arsenic in foods is in the neighborhood of 0.01 grain As_2O_3 per pound of food." This is many times more than could possibly be acquired from the drinking of water rising on this watershed. Contact with and breathing the dust was not particularly injurious, although unpleasant, and was so amply demonstrated by the fact that the men dumping the barrels of dust into the hopper and loading the plane, were enveloped in an almost constant cloud of dust for two weeks, yet experienced little ill effect from it.

In one case where a farmer's hay field was heavily dusted there was some justifiable fear that this would be fatal to his cow. A sample of the hay was analyzed by Prof. J. S. Jones, Chemist of the Oregon Experiment Station, and found to contain .115 grains of arsenic oxide (As_2O_3) per pound or 3.45 grains per 30 pounds - a daily feed

ration. Experiments have definitely shown that "horses and cattle can take, without any external evidence of injury or any alteration discernible upon the most careful post-mortem examination, from 20 to 30 grains of arsenic daily, month in and month out."[1] It is, therefore, extremely doubtful if the 3.45 grains per 30 pounds in this farmer's hay would have any injurious effect upon a cow although possibly fatal to smaller animals and about 10 times the allowable amount for human food.

Several reports were received that small animals, wild bees, birds and chickens had been killed by the dusting but these reports could not be fully substantiated. One or two small rabbits (Lepus Washingtoni Washingtoni Baird) were found dead immediately after the dusting under circumstances which suggested that the dust might be the cause. Also a number of gold finches were apparently killed by the dust, but no other birds appeared to be effected.

Determination of Results.

In order to determine the effectiveness of the airplane dusting some measure of the results was imperative. The method used by Swaine of spreading sheets under the trees and then delimbing the trees and counting the caterpillars appeared to be not only tedious and subject to considerable error but highly impractical when dealing with trees from 100 to 200 feet in height. It would be obviously impossible to take enough samples to have them truly representative.

Methods.

Adapting a method used in Germany to conditions on this area, muslin squares, 10 square feet in area, were established at numerous points through the forest and under varying conditions of crown canopy. Daily collections of the accumulated larval droppings were then made. These were strained to remove leaves, twigs, etc., soaked in water and then allowed to precipitate in test tubes. It was found that after 24 hours the droppings settled to the bottom and lighter material came to the top, so that the volume of saturated droppings could be accurately measured in cubic centimeters. This measure of the number of caterpillars feeding over any frame proved to be a very consistent one and graphs made of daily records show a steadily increasing volume as the caterpillars increased in size.

Concurrently with this field record, two sets of 100 larvae were confined in glass jars, fed, and their daily volume of excrement measured. (Chart #5) That these larvae were not materially affected by confinement is attested by the fact that they thrived and could

[1] Reeves, G. I. "The Arsenical Poisoning of Livestock" Jour. Econ. Ent. Vol. 18, No. 1, P. 83, Feb. 1925.

easily have been brought through to maturity had it been possible to continue these investigations. The volume of dropping from a known number of larvae became the index used to determine the number over any frame.

Number of Loopers per Acre.

The number of loopers over any frame was determined by the amount of droppings and the known amount of droppings from 100 larvae. The intensity of feeding varied from a very few loopers to millions per acre. Some of the heaviest frames gave records as follows:

TABLE NO. 6

	Loopers per Frame (10 sq.ft.)	Loopers per Acre
Frame #20 - July 18	5,000	21,800,000
" #16 - " "	3,600	15,700,000
Average undusted July 18	720	3,100,000
" dusted " "	260	1,100,000

On the heaviest feeding area (Frame #20) 3500 cc of dropping fell during the feeding period from June 8 to September 8. On dry weight basis these weighed .3 grams per cc. The total weight of droppings, therefore, on this 10 foot square was 990 grams (2.1 pounds) or 4.5 tons of droppings per acre.

Mortality Figures.

The first check frames were put in place on June 20th and after some experimenting with weighing and counting, the volume measure was adopted. Records were then secured starting with the 24th giving 10 days of records, before dusting started on July 3rd. These records were continued daily until July 25th. Then, due to unavoidable absence, the frames were not collected again until August 21st, when the total accumulated droppings were measured and another short set of daily records taken. Apparently the period August 21st to 25th was just after the peak of feeding as the daily amounts were then declining. After another lapse, records were taken on September 16th and 17th. These showed that the feeding was practically complete.

Charts 2, 3 and 4 group these records according to light, medium and heavy infestations and show what happened to the loopers when no dusting was done or where light and heavy doses were applied. The effect of the dust is very obvious.

Translating the record of droppings into terms of number of loopers over each frame before and after dusting, the figures shown in Table #7 were secured. The record of dosage was taken directly from

the field notes and simply indicates the opinion of the observer as to the quantity of dust applied. There was no accurate method of measuring the amount of dust applied over any frame and in some cases, notably Plot #6, it is more than probable that this should be listed as two medium heavy doses instead of two light ones. Nevertheless, the correlation between this field observation and the number of loopers killed and the percentage of reduction secured is very striking. Obviously where the dust was heavily applied the mortality was the greatest, averaging 82 per cent kill on the four most heavily dusted plots.

Taking all plots together, since they were all supposed to have been dusted, the kill averaged 45 per cent. Whether these 17 plots represent a fair average of the entire area dusted, it is very difficult to say, but it is the opinion of the writer that for the entire area north of the Hazelle River, this per cent of kill is approximately correct

TABLE NO. 7

Results of Airplane Dusting
in
Relation to Dosage

Dosage	Plot #	No. of Loopers Per 10 sq.ft.Plot Before	After	Number Dead Loopers	Percent Reduction
None	13	960	960	14	0%
"	14	920	880	14	4%
"	11	1,560	1,480	25	5%
"	15	530	480	5	9%
Total	4	3,970	3,800	56	4%
One very light dose	12	870	740	13	15%
One light dose	10	1,040	900	10	13%
" " "	16	3,940	3,150	32	18%
" " "	2	980	790	20	19%
" " "	1	960	670	52	30%
Total	5	7,690	6,250	127	19%
Two very light doses	3	620	330	32	47%
Two light doses	17	1,100	760	52	31%
" " "	6	3,920	1,250	291	68%
" " "	7	600	120	22	80%
Total	4	6,240	2,460	377	61%
Two medium heavy	4	1,830	470	233	74%
Two heavy	8	670	180	22	73%
Two extra heavy	5	2,010	290	550	86%
" " "	9	2,320	230	115	88%
Total	4	6,830	1,220	898	82%
Total undusted	4	3,970	3,800	56	4%
" Dusted	13	20,750	9,910	1,402	52%
All plots	17	24,750	13,710	1,458	45%

Problem of Dust Distribution.

After the dusting had progressed for three days, and early results were available, it became apparent that the greatest difficulty to be met was the matter of securing a uniform coverage. The area is an almost impenetrable jungle, almost totally devoid of openings or observation points, so that all previous methods of placing strip markers to guide the plane were impractical. The only thing that could be done was to lay out a natural topographic unit on the aerial map, figure the dosage at 20 pounds per acre, necessary to cover that area and then leave it to the skill of the pilot to distribute it as evenly as possible. Flying on area in parallel strips was absolutely impossible, due to the rough topography, irregular ridges and canyons which only permitted the pilot to maneuver the plane according to the configuration of the terrain and the local wind currents. The dust showed plainly enough on the tree tops and remained visible for about two hours, so the pilot could locate his previous strip and lay the next one down as closely adjoining it as possible.

As a consequence of being unable to place the dust at regular intervals, the coverage was inevitably patchy. Flight lines criss-crossed and even when lines were flown approximately parallel the dust settled unevenly, sometimes drifting to the right and sometimes to the left, depending upon wind currents. It also spread out unevenly, depending upon the distance of the plane above the ground. On crossing canyons dust sometimes spread out thinly to a width of 1000 feet, while on the tops of ridges where the plane was close to the tree tops it might all fall within a width of 100 feet. In one case four flights were made directly over a marked tree but no visible amount of dust was caught on a frame down the hill and less than 50 feet away. Each dust cloud drifted up the hill and settled at varying distances on the other side of the ridge.

Because of the action of the dust it was impossible to even estimate the amount of dust that reached the foliage directly over any plot. The only approximation that could be made was the amount applied to any given topographic unit. And the results on the different units were more or less proportional to the dosage. These results are shown in Table #3, which indicates that the heaviest kill was secured on Section 14 and the lightest kill on the plots of Section 32.

TABLE NO. 8

Results of Airplane Dusting

on

Different Sections

Sections	Number of Loopers Per 10 sq.ft. Plot Before	After	Number of Dead Loopers	Percent Reduction
Sec. 2, T. 11 N., R. 10 W.				
Plot 1	960	670	52	30%
" 2	980	790	20	19%
" 3	620	330	32	47%
" 9	2320	280	115	88%
Total	4880	2070	217	58%
Sec. 12, T. 11 N., R. 10 W.				
Plot 16	3840	3130	32	18%
" 17	1100	760	32	31%
Total	4940	3890	64	21%
Sec. 13, T. 11N., R. 10 W.				
Plot 8	670	180	22	73%
Total	670	180	22	73%
Sec. 14, T. 11 N., R 10 W.				
Plot 4	1850	470	253	74%
" 5	2010	290	550	86%
" 6	3920	1250	291	68%
" 7	600	120	22	80%
Total	8360	2130	1076	75%
Sec. 32, T. 11 N., R. 9 W.				
Plot 10	1040	900	10	13%
" 11	1560	1480	23	5%
" 12	870	740	15	15%
" 13	960	960	14	0%
" 14	920	880	14	4%
" 15	530	480	5	9%
Total	5880	5440	79	7%
Total all Plots	24,730	13,710	1458	45%

Speed of Poisoning.

To determine how long it takes after loopers have been fed poisoned foliage before mortality sets in, 100 loopers were placed in a jar and fed hemlock foliage which had been dusted with the calcium arsenate. The rate of mortality was as follows:

TABLE NO. 9

Hours after Exposure	Number Dying Each Period	Total Percent Dead
24 hours	7	7%
48 "	69	76%
60 "	14	90%
88	8	99%
120 "	1	100%

In the field the same tendency was evident, with the heaviest mortality occurring the second and third days after dusting, and a decreasing effectiveness as time went on. The death of larvae due to eating poisoned foliage was still evident on the heavily dusted plots two weeks after dusting. On more lightly dusted plots, no noticeable effect could be observed after the first week.

General Results.

At the time the dusting was completed signs of defoliation were just starting to become visible. But in the following four weeks, the loopers which escaped death increased the amount of their daily feeding and their inroads into the trees' foliage became very apparent. Then it was possible to see how well we had guessed whence the new broods of loopers had been and how effective the dusting had been over the general area and to what extent timber had been saved.

On September 19th, through the kindness of the Forest Service, the fire control plane was loaned for two hours of observation flight over the area, there still being some available hours under the minimum specified in their contract. The Northwest Air Service also had this contract, and Mr. Blum, who had contracted the dusting, piloted Mr. Cowan, Mr. George Long and myself over the now familiar looper area.

The results were about what had been anticipated. On the areas known to have received a heavy dosage no further defoliation had occurred. On other areas the new defoliation was in streaks, alternating with green strips, so that from the air one could almost mark out where the dust clouds had been placed and what areas had been missed. Of particular interest were the two areas where attempts had been made to fly the plane along strips at 140 foot intervals. In these places the coverage had been complete and noticeable defoliation had been satisfactorily prevented. It is unfortunate that more of the area could not have been covered in this manner but, as stated before, this was absolutely impractical.

A number of new extensions of the outbreak were discovered from the air. These areas were far removed from old centers and so at the time of dusting there was no possible way of determining their extent. The infestations in Section 3, T. 11 N., R. 10 W. and Section 25, T. 12 N., R. 10 W., which were first discovered from the air and later examined on the ground, had been partially dusted. These now proved to be much larger centers than had been anticipated. The area south of the Naselle River received very little dust in proportion to the infested area and this showed considerable extension of the old defoliated areas with many patches joining together to form almost solid blocks of dead forest.

Any estimate as to the amount of timber saved through this year's dusting by its very nature would have to be a mere guess, for there is no possible way of determining how large an area would have been killed if no work had been done. The plots indicate that a 45 per cent reduction was secured. Referring to Table #1, it is reasonable to expect that the area killed this year would have been as great as that heavily infested last year; or, in other words, that the work saved timber equal to that on 3000 acres from destruction, or approximately 90 million board feet. The cost of saving this timber was, therefore, about 15 cents per M. B.M. Even if only half this amount of timber was saved and with hemlock worth 50 cents per M., the dusting operations would still show a profit.

THE OUTLOOK FOR NEXT YEAR.

The extent of looper activity during the 1931 season is now fairly well known. Loopers have been found working to some extent in an area of approximately 32,000 acres (see attached map) centering around the Naselle and Nemah Rivers. Heavy defoliation has occurred on 11,500 acres. In addition, a new outbreak covering 20,000 acres in Grays Harbor County has been discovered. With the flight of moths, this fall, eggs may have been laid over a far wider territory, so it is impossible to say how many acres are now affected.

The infestation is now so widespread that any further control through airplane dusting would be highly impractical. Fortunately, it is more than likely that no further control will be necessary and that 1932 will see the last remnants of the looper epidemic, if not its complete extinction. There are several indications which point to that conclusion.

Parasites.

Parasites are much more abundant this year than last. Caged larvae and pupae showed the following per cents of parasitism:

TABLE NO. 10

		Moths Emerged	Parasites Ichneumon	Parasites Diptera	Percent Parasitized
Jar 1,	Larvae collected August 20	55	6	6	19%
" 6,	Larvae collected September 3	6		1	14%
" 7	Prepupal larvae collected Sept. 3	31		1	3%
" 8,	Pupae collected September 3	150	94	19	43%
" 9,	Pupae collected September 4	35	15	8	40%
Total		277	115	35	55%

The most common ichneumon parasite was a dark red species, probably Amblyteles cestus Cress. Another undetermined black species of Ophialtes was reared from the pupae. The Diptera or fly belonging to the family Tachinidae has not been officially identified as yet.

Even with a parasitism of 55 per cent, billions of pupae would still be unaffected and make possible a heavy emergence of moths and egg laying. While parasitism is, of course, important, it cannot be expected to control the species until a much higher per cent of loopers are affected. Parasitism does show a rapid increase over last year and parasites should be plentiful enough to be a control factor of major importance in another season.

1931 Flight of Moths.

The flight period of the adults is the one weak link in the life history of the hemlock looper. Heavy rains at that time beat down the fragile moths and prevent them from mating and laying eggs.

Since the flight normally occurs during October, the amount and distribution of rainfall during that month is a very important factor in determining the continuation of a looper outbreak. So a study of weather conditions during October should yield some profitable information, and indicate the future trend of the looper outbreak.

Normally October is a very rainy month in this coastal region, and this may account for the usual scarcity of loopers. Observers of

the Tillamook outbreak in 1919 to 1921 report that the heavy rains of October 1920 were largely responsible for the breaking up of that outbreak.

Rainfall at Astoria, Oregon

	October Rainfall	
1916	2.51	
1917	1.25	
1918	3.18	Beginning of looper outbreak.
1919	3.52	Increasing losses
1920	12.80	Last year of heavy losses.
1921	7.02	End of outbreak.
Normal	5.65	

The weather records of Pacific County show that during recent years, October has been below normal in rainfall, so that the flight of moths has been uninterrupted. However, this year the rainfall returned to normal and the flight was of short duration. Beginning with September 27th the weather continued cloudy and rainy until October 6th. Then until October 16th there were ten days of fairly clear weather during which a flight of moths occurred. This was brought to a close as rains commenced again on the 16th and continued until the 29th of the month. When Buckhorn visited the area on November 5th he could only find about a dozen moths still in evidence while last year on the same date the ground and pools were literally covered with them.

Rainfall in Pacific County During October

	North Head	Naselle	
1926	5.93	-	
1927	5.61	-	
1928	4.89	-	Looper outbreak started.
1929	1.83	2.88	Increased defoliation.
1930	7.26	5.87	" "
1931	5.69	13.69	" "
Normal	5.01	-	

The above normal rainfall of this past October and the very short period for flight and egg laying is a very hopeful indication that the peak of the hemlock looper outbreak has already been passed.

CONCLUSIONS.

The airplane dusting project carried out this year in the Naselle area, although based upon the successful experience of other projects in the eastern United States and Canada, involved many experimental angles in its application to conditions in virgin forests of the Washington coast. However, it demonstrated the feasibility of airplane dusting as a method of controlling forest defoliators in commercial forests and also showed certain definite accomplishments.

The project demonstrated that through careful planning and execution of the mechanical side of the work dusting of calcium arsenate at the rate of 20 pounds per acre can be done at a cost not to exceed $2.75 per acre or a cost of protection of approximately 9 cents per M. B.M which is a very reasonable expenditure to make to protect valuable timber.

The work also demonstrated that calcium arsenate dust will kill the hemlock loopers effectively and prevent wholesale defoliation and killing of timber if applied in a heavy enough dosage. In the present instance it is estimated that an average reduction of 46 per cent was secured over the entire area dusted with a 20 pound dosage and some plots showing a kill in excess of 80 percent where a dosage of about 55 pounds per acre was used.

The project also demonstrated the need for improvements in certain features of the work. There is a distinct need for a dust with better adhesive qualities than calcium arsenate possesses. If the dust had remained on the foliage longer, the mortality of caterpillars would undoubtedly have been heavier. With the dust used on this project and its lack of good adhesion fully twice the dosage was needed to give a high percentage of kill. With the higher trees and increased density and volume of foliage present on an acre of Washington coast timber, a heavier dosage than that used in the eastern work would probably have given a heavier kill. The uniform application of the dust is another weak point which requires further study. Some method of marking an area needs to be devised that can be used under the conditions found on this area.

On the whole the dusting project was well worth while. It is estimated that it resulted in saving at least 90 million board feet of timber from destruction this year. It also demonstrated the strength and weakness of airplane dusting as a control weapon against forest defoliators, and at the same time brought results in timber saved which in themselves should fully justify the expenditures made.

F. P. KEEN
Entomologist.

Portland, Oregon
December 10, 1931

CHART NO. 1

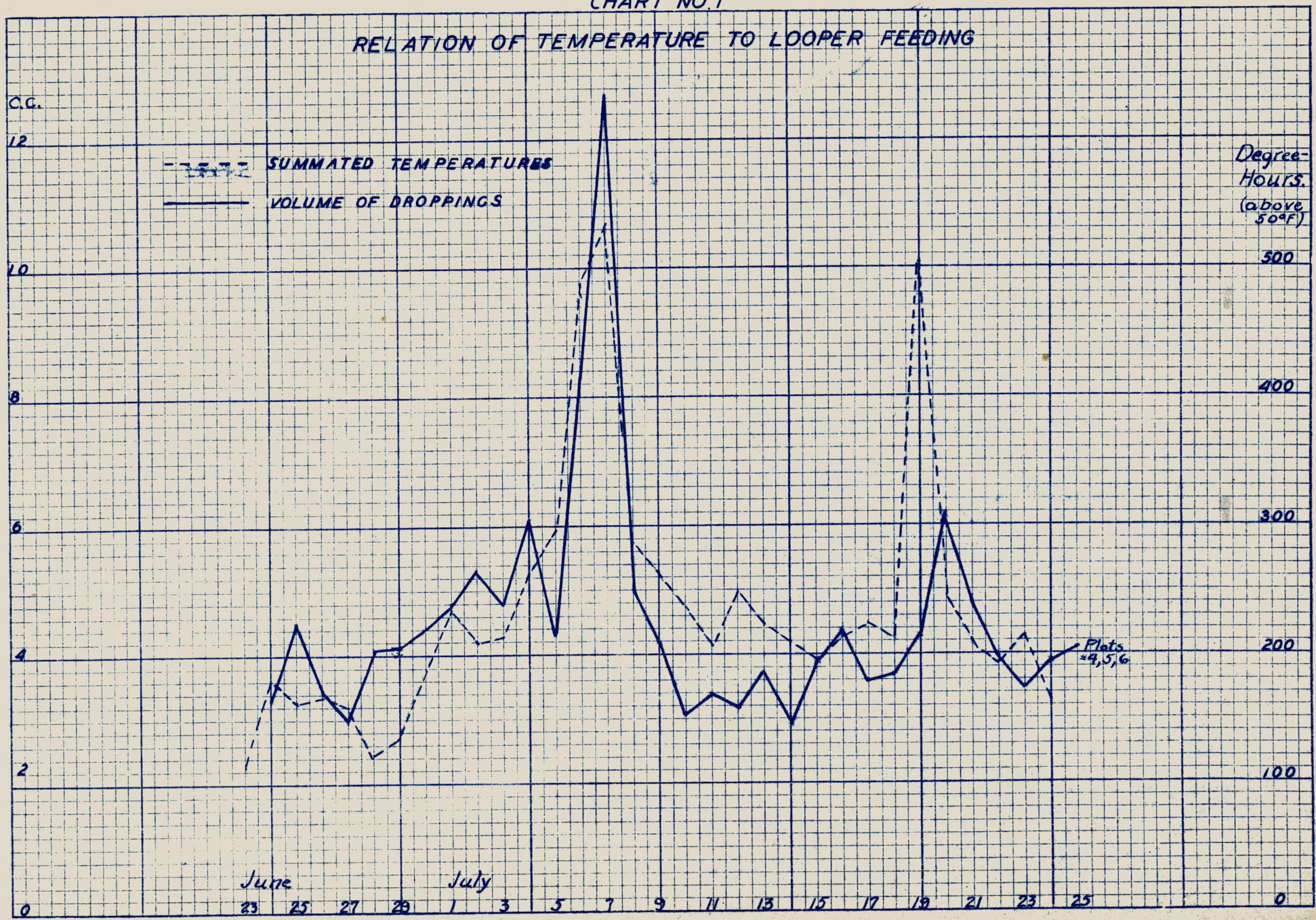
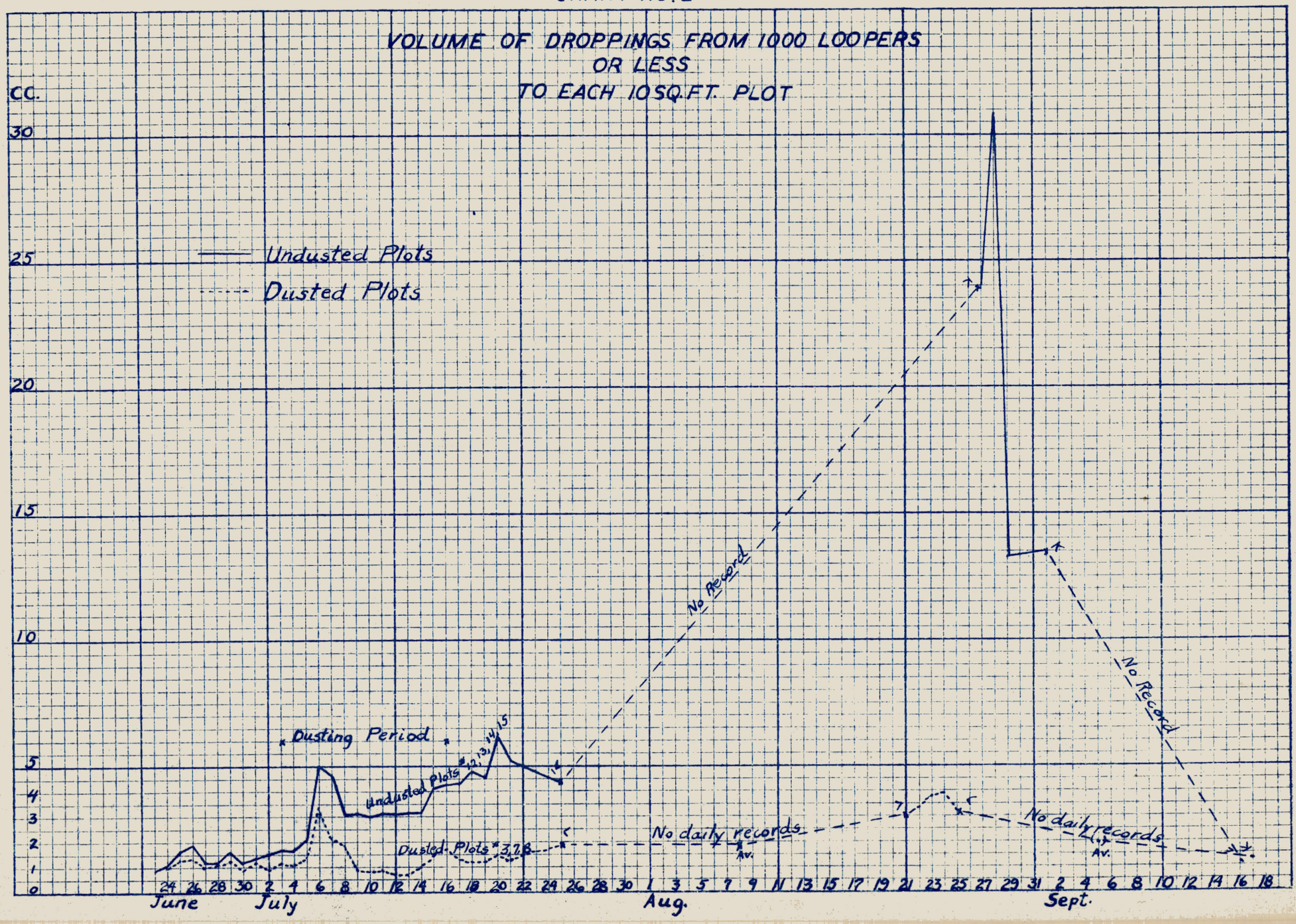


CHART NO. 2



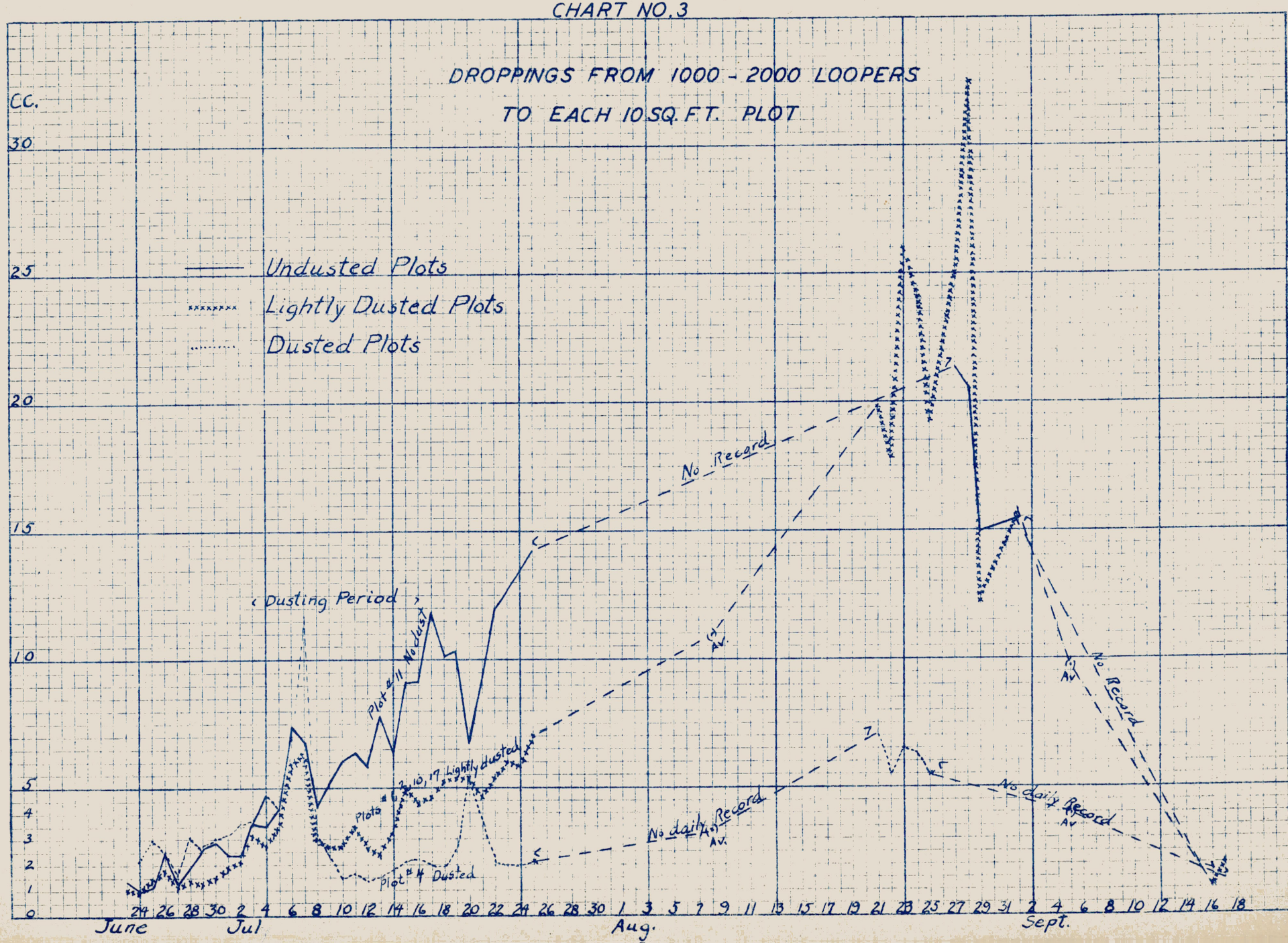


CHART NO. 3
DROPPINGS FROM 1000 - 2000 LOOPERS
TO EACH 10 SQ. FT. PLOT
CC.
30
25
20
15
10
5
4
3
2
1
0
Undusted Plots
Lightly Dusted Plots
Dusted Plots
Dusting Period
Plot # 11 No dust
Plots # 3, 10, 17 Lightly dusted
Plot # 4 Dusted
No Record
No daily Record Av.
No daily Record
No Record
Av.
24 26 28 30 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 2 4 6 8 10 12 14 16 18
June
Jul
Aug.
Sept.

CHART NO. 4

INFESTATIONS OF OVER 3000 LOOPERS TO EACH 10 SQ. FT. PLOT

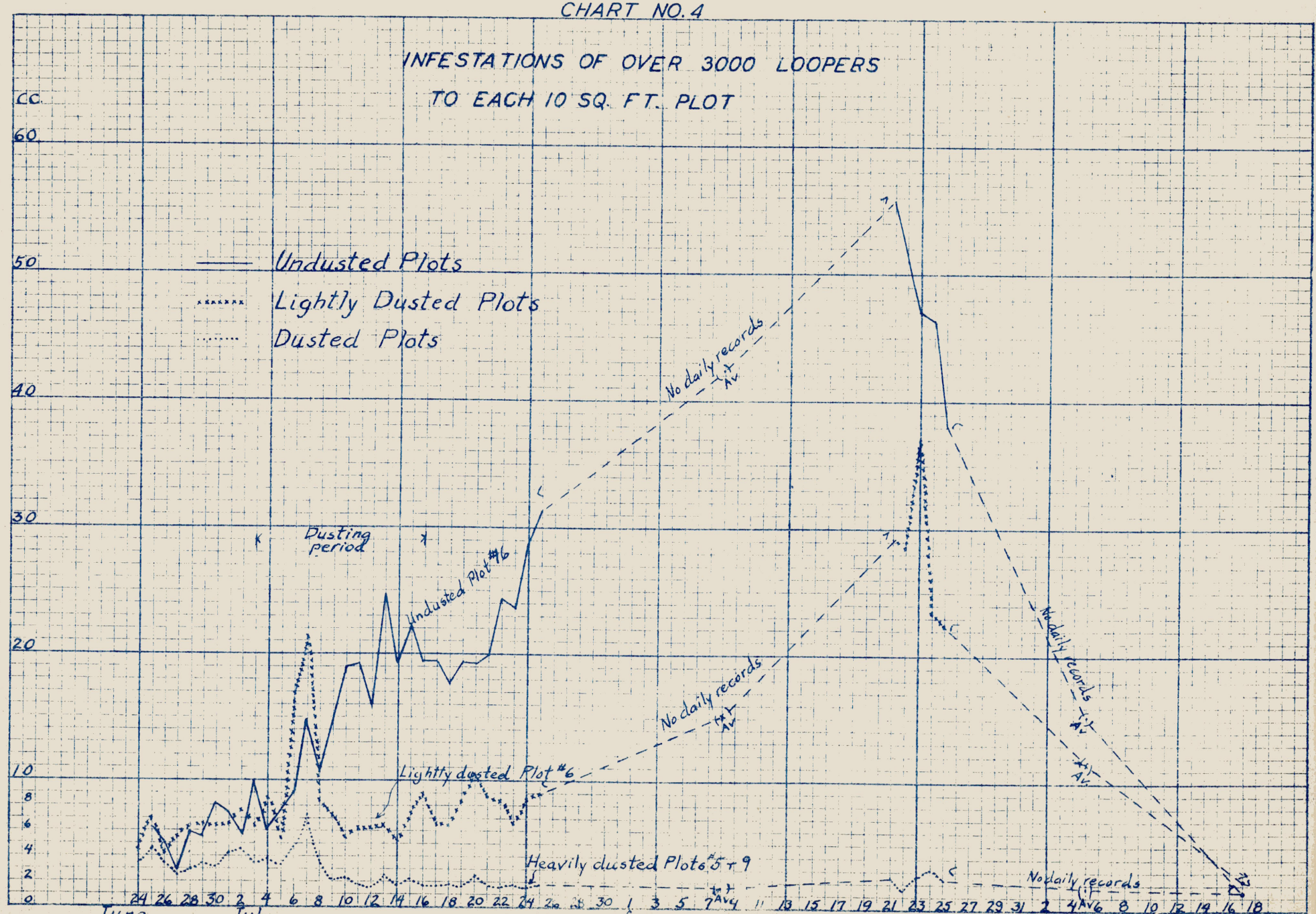


CHART NO. 5

INCREASE IN VOLUME OF DROPPINGS FROM 100 LOOPERS PER DAY